CONCEPT OF NASA SPACE NETWORK (SN) SUPPORT FOR RANGE SAFETY

Ted Sobchak
Code 451, NASA/Goddard Space Flight Center
Greenbelt, MD 20771
Tel: +1 301 286 7813; Fax: +1 301 286 0275
E-mail: ted.c.sobchak.1@gsfc.nasa.gov

John Smith
Lockheed Martin/Goddard Corporate Park
7515 Mission Drive
Seabrook, Maryland 20706
Tel:+1 301 805 3111;Fax: +1 301 805 3443
E-mail: john.a.smith.1@gsfc.nasa.gov

Doug Lumsden
Lockheed Martin/Goddard Corporate Park
7515 Mission Drive
Seabrook, Maryland 20706
Tel:+1 301 805 3551;Fax: +1 301 805 3443
E-mail: douglas.r.lumsden.1@gsfc.nasa.gov

Abstract:

Range safety functions are performed at virtually all ranges (i.e., launch locations) nationally and internationally. The current method of providing command destruct and telemetry for U.S. ranges requires ground based antenna systems to maintain an Ultra-High Frequency (UHF) RF link with the vehicles for the purposes of transmitting commands to the launch vehicle to initiate ordnance, negate thrust, or otherwise destabilize the launch vehicle. At several U.S. launch facilities, range safety extends to orbital insertion for space-lift, a function requiring multiple downrange Flight Termination System (FTS) ground assets located in remote areas. The operational expense and technical complexity of these systems discourages the construction of new ranges.

The consideration of the shortcomings of the current range safety systems and services has led to the investigation of alternative concepts. The NASA Goddard Space Flight Center (GSFC) is exploring the idea of a space-based platform to support Range Safety communications for Expendable Launch Vehicles (ELV) and Reusable Launch Vehicles (RLV) as a flexible and cost-effective solution. The focus of the project is on the development of a demonstration system that can be used on proof-of-concept flights and experiments. The new concept is expected to include the capability to simultaneously track numerous signals at the launch vehicle. These signals will include: 1) flight termination commands from both space and ground assets; and 2) tracking signals from Global Positioning System (GPS) satellites.

This paper introduces the concept of using the NASA Space Network (SN)/Tracking and Data Relay Satellite System (TDRSS) as the space-based platform to support range safety activities for the Eastern Range (ER), Western Range (WR), and other new launch locations. A technical overview will discuss how this approach can meet current range safety requirements, such as static geometric forward and return link margins, data latency, and data security. A space-based range can prove more cost-effective by shortening the interval between launches and reducing the amount of ground-based assets needed for existing and planned ranges. Also addressed are technologies currently under development that can implement this concept, as well as plans for demonstrating a proof-of-concept system.

I. Introduction

Range safety service can be defined as those services provided at a launch range that maintain the integrity of the launch system (both vehicle- and ground-based) and avoid threat to human life. The range safety communications systems are used to receive inertial guidance data and system health status transmitted from the vehicle, and to transmit command data to the vehicle to invoke action in the event flight termination is required. In the process of providing range safety services, the position and health of the vehicle are compared to critical safety parameters to determine appropriate action. In the case of Expendable Launch Vehicles (ELV), that action may involve flight termination by detonation of pyrotechnics to destroy the vehicle before causing harm to human life. Flight termination has also been extrapolated into an operations concept for Reusable Launch Vehicles (RLV), whereby the vehicle propulsion system is disengaged to allow for a controlled re-entry. The idea can be further expanded to include critical communication for RLVs from launch through orbit to re-entry and landing.

The current range safety system, though effective for many years, can benefit from new technologies and capabilities. The obsolescence and cost of the current system has caused U.S. launch range services to be less competitive in a highly competitive world launch market. Apart from high operations and maintenance costs, other pressures for upgrading the current system are UHF frequency crowding, inconvenient ground asset locations, and the need for greater flexibility in selecting new range sites. Enter the concept of a more flexible, more robust, technologically advanced system that, in addition to the current range safety services, offers reliability and global coverage – a space-based range.

The concept of a space-based range safety support system espoused in this paper was developed by the NASA Goddard Space Flight Center (GSFC) Space Network (SN) Project Office, in association with Kennedy Space Center Advanced Range Technologies Office, the Eastern and Western Ranges, and commercial industry. Space-based range support could certainly augment, and even eliminate, the extensive downrange ground-based tracking systems used today, saving millions of dollars in operations and maintenance costs.

II. History/Background

Since the inception of the United States Space Program in the late 1940s, the U.S Department of Defense (DOD) has provided ground-based range safety support on all Major Range and Test Facility Bases (MRTFB). This was because the DOD was initially the only agency involved in the U.S. launch activities. Increasing launch requirements from commercial and non-DOD agencies have led to the development of several different launch and missile ranges.

The range safety systems evolved into the current safety system, which relies on an extensive network of ground stations located along launch ascent profiles. Various characteristics of current range safety systems and services have led to several investigations of new concepts of range safety support. A few of the driving factors for new concepts include the costs associated with maintaining range safety stations (especially remote stations and those located on non-U.S. territory), ground station horizon coverage limitations, and current range safety UHF frequency band crowding.

The NASA GSFC investigation of SN support to range safety stems from the success of providing telemetry return link services to ELV launches for the vehicle upper stage starting in 1994. High quality telemetry is provided by TDRSS over a longer period of the mission than by any other means, such as ground stations or aircraft. The TDRSS operational signal margins were larger than initially predicted. As a result, several projects abandoned their requirement for other sources of telemetry (e.g., Advanced Range Instrumented Aircraft - ARIA).

The natural next step following the success of the telemetry support was an inquiry into the possibility of providing a forward link service such as command destruct. Work began in 1996 by the NASA Goddard Space Flight Center (GSFC) on a Concept and Feasibility study that was released in June 1998. This initial study focused on TDRSS services for range safety telemetry and command destruct for ELVs at the Eastern Range and Western Range, with consideration given to services provided to remote launch ranges. The Concept and Feasibility study baseline analysis investigated the use of TDRSS as a space-based range; as well as the development of an S-band launch-head station, an S-band multi-channel receiver, and other launch vehicle equipment. Support for the concept grew in the range communities and has led to a partnership with range authorities and safety officers to examine the concept and develop flight experiments. Additional interest from various RLV development groups initiated an expansion of the study to include concepts to provide a critical communication channel for all mission phases.

III. SN/TDRSS Overview

The SN/TDRSS network provides global coverage for forward and return link services to a multi-mission environment. The network supports Low Earth Orbiting (LEO) satellites, ELV launches, and special experiments such as ground relays (South Pole), aircraft, and high altitude scientific balloons. The TDRSS is comprised of two segments. The Ground Segment, and the Space Segment.

<u>The Ground Segment.</u> The Ground Segment is located near Las Cruces NM, and consists of two co-located ground terminals known as the White Sands Complex (WSC). Each ground terminal consists of three Space Ground Link Terminals (SGLT) for a total of six. One of these SGLT is located at Guam, USA, and is remotely controlled as an extension of the WSC. The addition of the Guam Remote Ground Station (GRGT) eliminates the previously existing zone of exclusion (ZOE), which was a geometrical RF exclusion area over the Indian Ocean (Figure 1). Each SGLT is assigned to a Tracking and Data Relay Satellite (TDRS) spacecraft for satellite housekeeping and user services. All user data is relayed from the launch vehicle via the TDRSS to the WSC and then on to the ROCC.

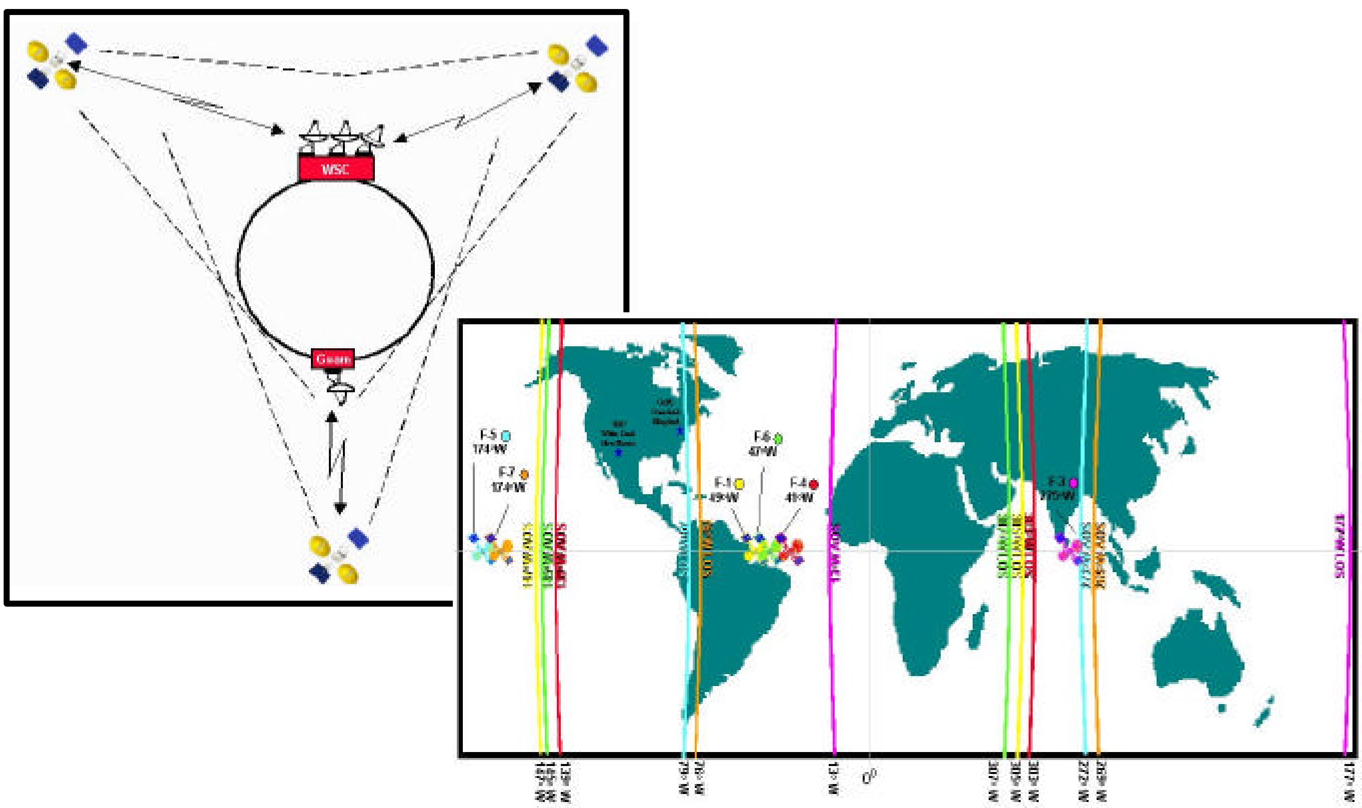


Figure 1. TDRSS Global Coverage and TDRS Locations

The Space Segment. The Space Segment consists of five TDRS spacecraft in geostationary Earth orbit (Figure 2). These TDRSs are strategically placed to provide global RF coverage for support of user spacecraft and vehicles. From this altitude, the TDRS has an S-band RF "footprint" that is approximately 700 miles in diameter at the Earth's surface. The TDRS Single Access (SA) antenna is programmed to track preflight nominal trajectories; and can be updated by solutions derived from onboard GPS or inertial measurement units (IMU), radar, or other tracking sources. Based on the predicted trajectory, both the forward and return link signals are doppler compensated to aid acquisition. The launch-head and TDRSS will operate in a to-be-identified Forward frequency between 2025 to 2120 MHz, and Return frequency of 2200 to 2300 MHz

TDRS Spacecraft Description - Key components of the TDRS spacecraft are identified in Figure 2.

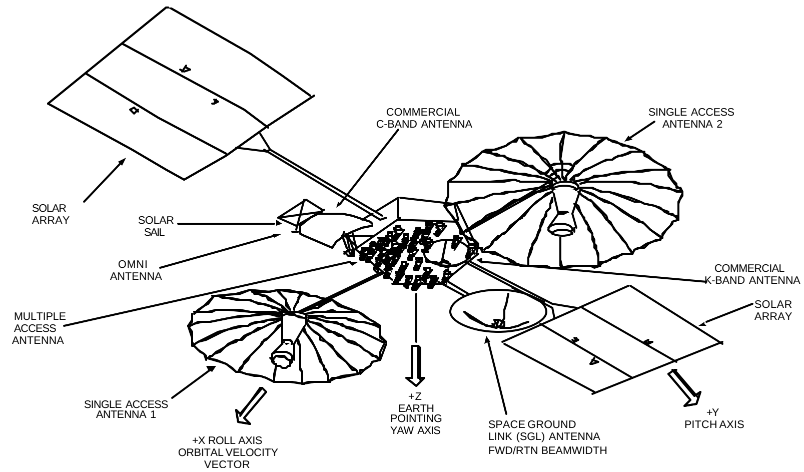


Figure 2. TDRS Description

SN/TDRSS Support Elements - The SN support elements included in the range safety concept are the Network Control Center (NCC), Flight Dynamics Facility (FDF), and NASA Integrated Services Network (NISN). Figure 3 depicts the SN elements interfaces to support the SN range safety concept. The responsibilities for each supporting element are described below:

NCC.	Located at GSFC, the NCC is the point of contact for all networks planning, scheduling, and control.
FDF	Located at GSFC, the FDF is responsible for TDRS and User spacecraft ephemeredes and tracking data.
NISN	Managed from MSFC with personnel at GSFC, the NISN provides all communication circuits between operations entities.

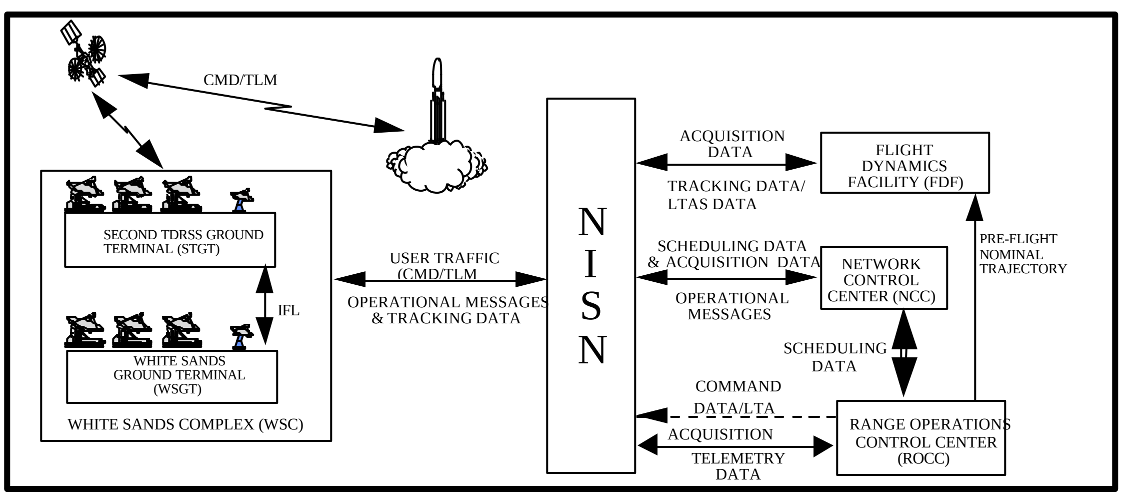


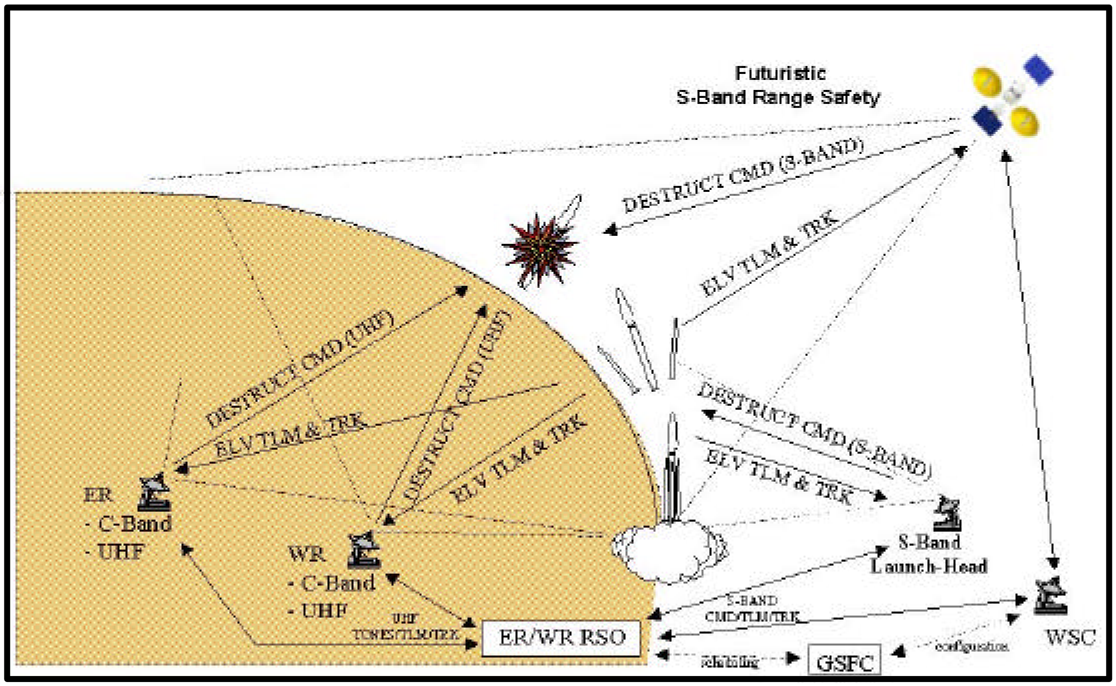
Figure 3. SN/TDRSS High Level Overview

IV. Proposed Space-Based Range Safety

The TDRSS constellation of geostationary satellites has the capability to provide global S-band coverage to U.S. Eastern and Western Ranges, as well as to other missile ranges, future commercial spaceports, and other remote launch locations. Following is a high-level discussion of SN/TDRSS range safety support scenarios and parameters, such as: link margin, data latency, security, radio frequency interference (RFI), and TDRSS reliability.

Concept Description

The concept involves a transition from a ground-based range safety system with downrange assets for handover of services between ground stations to a space-based platform that provides continuous support with global coverage. Significant changes are the reduction in ground assets, introduction of new technology, the use of digital commands, and a shift from a UHF ground-based system to a launch-head/space-based S-band system (Figure 4). The GSFC space-based configuration includes the TDRSS, a ground based launch–head, and compatible vehicle communication equipment.



Current range safety communications requires a network of ground stations located along the flight trajectory. Located in geosynchronous orbit, a single TDRSS spacecraft can track along the ascent profile from liftoff to main engine cutoff. The TDRSS constellation can provide complete tracking through on-orbit operations, decent, and landing, for reusable launch vehicles.

Figure 4. Current vs. Proposed Range Safety System

Main Components

The current TDRS constellation consists of five satellites in geosynchronous Earth orbit, which provide global S-band Forward (CMD) and Return (TLM) RF coverage. A single geosynchronous TDRSS spacecraft can provide coverage from launch vehicle liftoff to main engine cutoff, while the TDRSS constellation can provide continuous coverage throughout ascent, orbital operations, and landing. The range safety concept uses the TDRS Single Access (SA) system in the high power mode to transmit commands and receive telemetry. Each of the current TDRS in the constellation has two SA antennas, each of which can support an S-band and Ku-band service simultaneously. This range safety support concept focuses on S-band services. Figure 5 shows an example of TDRSS coverage.

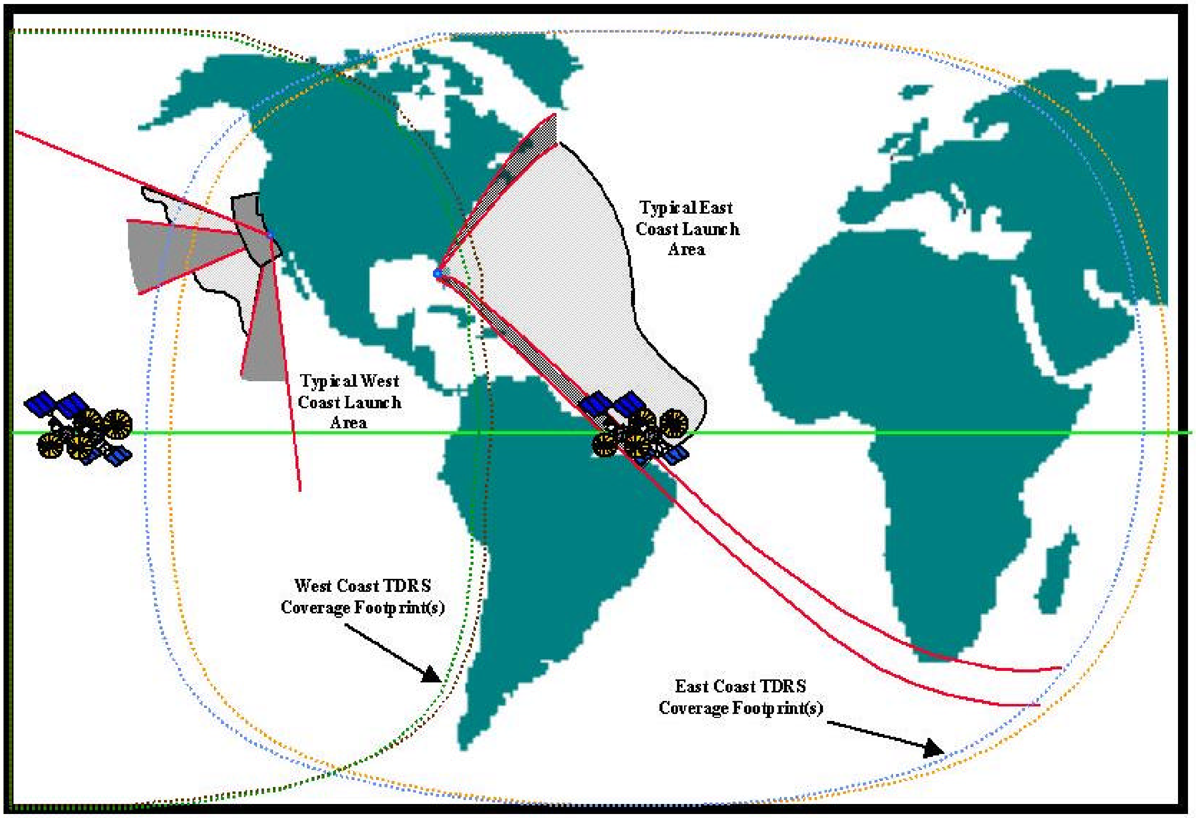


Figure 5. Example TDRS Coverage Overlay to the East Coast/West Coast Launch Area

Supplementing the space segment of this system, a TDRSS-compatible launch-head system will be used at the launch site. The purpose of the launch-head system is to provide prime communications while the vehicle is on the launch pad. This system will be the focal point of all range command and telemetry until TDRS acquisition, and will provide simultaneous support with TDRS until loss of signal due to horizon limitations. The launch-head system will provide communication at a higher radiated power from launch until loss of signal. An S-band launch-head compatible with TDRSS will allow a seamless transition of services to the TDRS spacecraft once the vehicle is over the horizon and the launch-head loses communications.

The launch-head system will also be a valuable asset in pre-launch test activities. The S-band launch-head will provide a system available for pre-launch checkouts and will alleviate the need to use the on-orbit TDRSS resources.

The launch vehicle will carry a fast-acquisition, multi-channel transceiver with S-band and L-band frequency inputs. The multi-channel transceiver will receive multiple signals from ground and space resources simultaneously: commands from the launch-head and TDRSS; and position data from GPS. The transceiver will transmit position and range safety data at S-band to be received by TDRSS and the launch-head system. At the Range Control Center, the data is used by the Range Safely Officers to determine a course of action.

Operations Scenario

While the vehicle is on the pad, the launch-head station will provide prime support. After the vehicle is clear of the launch pad and the interference and multipath effects due to that structure sufficiently subside, the vehicle will acquire the TDRSS signal. The launch-head and TDRSS will simultaneously radiate S-band, PN-spread signals that contain digital commands until the launch-head signal is dropped manually or until over-the-horizon loss of signal (approximately seven minutes into the launch). After the loss of launch-head coverage, the TDRSS will be prime throughout the rest of the ascent profile. Both the launch-head and the TDRSS command signals will be at the same frequency, but will use different PN codes. This code division multiple access (CDMA) scheme has been used in many applications, including the TDRSS multiple access (MA) return system. Both analysis and experimentation will be used to determine the optimal signal level for the launch-head so that it does not block the TDRS signal. On the other hand, some operations scenarios may call for boosting the launch-head signal above this level, followed by a stepped attenuation to allow the acquisition of the TDRS. Scenarios have been examined in which one SA antenna from a single TDRS or two antennas from separate TDRS spacecraft are employed.

The flight vehicle would carry two multi-channel receivers that would acquire and track the up to three TDRS mode PN spread signals. Additionally, the transceiver would track and process GPS signals from up to eight satellites. The receivers will process digital commands from the TDRS mode signals, such as check, arm, safe, and, of course, flight termination. The receiver will latch and safe the flight termination system as needed. Additionally, the transceiver will transmit the location and velocity solutions along with other vehicle range safety performance parameters to both the TDRSS and launch-head. The transmitted signal is a BPSK signal.

In the case of an RLV, the same transceiver would continue TDRSS communications throughout the duration of the mission, including descent and landing. Periods of communication blackout may occur during the descent due to plasma induced attenuation. But, through careful design of the antenna locations on the vehicle, these periods of blackout can be minimized, since two TDRS are in view of many potential descent locations.

Specific Operations Considerations

Analyses were conducted to determine if the TDRSS could be a viable option for space-based range safety support. The following operational considerations have been evaluated.

- o Static Geometric Forward and Return Link Margins
- o Data Latency Measurements
- o Security Considerations
- o TDRSS Reliability Data

A. Static Geometric Forward and Return Link Margins

The NASA GSFC TDRSS Range Safety Team utilized the *Communications Link Analysis and Simulations System (CLASS)* analysis tool to predict telecommunications systems performance based upon worst case range safety launch vehicle/TDRSS support characteristics. The TDRS SA link analysis was performed assuming a 250 bps command link data rate and telemetry rate of 2.4 kbps. For both the command and telemetry analyses, a minimum antenna gain which was exceeded over 95% of the vehicle RF coverage sphere was used. Therefore, for less than 5% of the coverage sphere the antenna gain will be lower than used in the analyses. A hybrid coupler was used between the antennas and the two receivers and resulted in the best analysis link margin. Assuming this configuration, for over 95% of the sphere, one (or both) of the receivers has a command link margin >10.8 dB. Over the other 5% of the sphere, both receivers have a margin that is < 10.8 dB. The telemetry analysis resulted in a 7.4 dB link margin.

The potential exists to use coding, such as convolutional coding, on the forward link to improve link margins. However, this may not be advisable due to the resulting increase in data latency. Analyses are being conducted to determine the optimum data rates for the command and telemetry links which may result in increased data rates and therefore may lower link margins.

B. Data Latency

Data latency is defined as the delay from the issuing of a command to the execution of that command. The delays intrinsic to the TDRSS and ground station hardware have been measured to be on the order of microseconds, a negligible number compared to the propagation delay between a ground station antenna and a TDRS. Latency measurements have been performed by sending digital commands from a simulated control center to the White Sands Complex (WSC), where they were processed, modulated, and transmitted on an RF carrier to a TDRS, and then retransmitted by the TDRS to a simulated launch vehicle. The total round-trip latencies measured in these closed-loop tests were 340-370 milliseconds, under the 500ms maximum required for current range safety operations. For these tests, serial data across existing terrestrial interfaces to WSC were used. The routing of these circuits were not designed to minimize latency and therefore further small decreases in latency may be possible.

C. Security Considerations

Security in the context of range safety is taken to mean both immunity from accidental RFI and protection against hostile jamming. The use of a space-based asset precludes the brute force approach used in the current UHF system of transmitting extremely strong signals to overwhelm any interference. Instead, PN spreading forward link signals with different orthogonal codes would permit the launch vehicle to receive two or more command signals at the same frequency from the launch-head and TDRSS, while also providing some jamming resistance.

A critical element of data security is the command data structure. A study is currently underway to determine the optimal combination of command length, latency, data rate, and link margin. The underlying trade-off in reaching the proper balance of these factors is that enhanced security usually entails longer commands, which in turn increases latency. The increase in latency can be offset by raising the data rate, but only at the expense of the link margin. For this reason, encryption might not be used on the forward link despite its security benefits.

The proposed space-based range safety concept would make it difficult for a vehicle to receive undesired commands, but offers no foolproof safeguard against a determined hostile jammer. NASA system security is in accordance with the NASA Handbook (NHB 2410.09 – NASA Automated Information Security Handbook), the GSFC Handbook GSFC 1600.1A and NSA Communication Security procedures.

D. TDRSS Reliability Data

TDRSS reliability is measured in terms of the mean time between failures (MTBF). The MTBF is calculated by dividing the 10-year cycle of a TDRS by the predicted number of failures. Equipment failure prediction is performed in accordance with *Reliability Prediction of Electronic Equipment MIL-HDBK-217D.* TDRSS reliability since 1983 has been measured to be 99.8% for operational supports. The TDRSS is designed with a high degree of redundancy. For instance, for every active event that TDRSS supports, both a prime and redundant chain of equipment at WSC process the user's signal. The TDRS constellation has performed better to date than the predicted failure model.

V. Cost Comparisons

Maintenance and operations cost for the current range safety is high. Driving these costs is the need for multiple downrange sites, with their associated equipment and maintenance personnel. Furthermore, since these sites focus primarily on supporting range activities, the operating costs are not shared among many users. The turnaround time between launches due to scheduling and equipment recycling also contributes significantly to cost.

Use of a space-based resource such as TDRSS can significantly reduce maintenance, operations, and associated turnaround costs. Since the TDRSS network is a shared resource, maintenance and operating costs are spread among numerous users. Because TDRSS is a ready resource, turnaround time required for services is minimal, reducing expenses even more.

VI. New Technologies

A TDRSS space-based range lends itself better than the existing system to the incorporation of new cost-cutting technologies. A cornerstone of the space-based range is a ruggedized S-band transceiver installed in a launch vehicle that is capable of receiving multiple simultaneous signals and transmitting telemetry. A variant of the Low Power Transceiver (LPT) developed by ITT Industries under contract to NASA GSFC (Figure 6) is a leading candidate for the flight demonstration phase. With modest changes in packaging and functionality, this low power, fast-acquisition transceiver can be adapted to the range safety application.

Figure 6. ITT Low Power Transceiver

The LPT is a modular, multi-channel unit capable of receiving 12 channels in S and L-bands. For the Range-Safety System, the LPT would be configured to receive up to 3 TDRSS-mode signals and 8 GPS signals with the remaining channel open. Although each channel can receive a spread or non-spread signal, for the SN RS concept all received signals will be PN spread. The transceiver will transmit data at S-Band using BPSK modulation compatible with the TDRSS. The final transmitter power output will be a function of the telemetry data rate required for the vehicle. The unit is roughly 5x5x5 inches in size, 5 kg in mass, and capable of operating in temperature ranges from -30° to 75° C. The unit is being designed with range requirements in mind including ruggedized housing.

VII. Proof-of-Concept Testing

GSFC is establishing initial plans for a Proof of Concept program. The GSFC test program will involve the SN/TDRSS network, the S-band launch-head ground system, and the launch vehicle component (i.e., the LPT) on a flight vehicle. Since the SN/TDRSS network provides services to numerous spacecraft, launch vehicles, and special experiments on a daily basis, baseline characterization test results will be used for comparison. A range safety S-band launch-head system will employ new technology, and so will require extensive testing by itself prior to use in the space-based platform concept testing. For the proof-of-concept testing, existing NASA resources would be used as a launch-head with special equipment attached to provide the TDRSS mode command link. The transceiver will be rigorously tested in a series of SN/TDRSS compatibility tests ranging from laboratory check-outs to wireless RF operation through TDRSS.

After successful completion of TDRSS compatibility tests, the unit will undergo environmental tests. The environmental testing will include shock and vibration testing, thermal vacuum testing to evaluate temperature performance; and high dynamics to assess general system performance and the ability of the unit to acquire in a critical environment. Additionally, failure modes and effects analysis, along with part and materials analysis, will be performed. The intention is to use the worse case environmental requirements as the design goal.

After successful completion of environmental testing, the unit will be ready to begin flight test activities. The proof-of-concept program culminates in the flight test, the objective of which is to demonstrate the performance of a fully integrated space-based range safety system by installing a transceiver in the payload bay of a flight vehicle.

For the purposes of flight demonstration, the onboard range safety system will be entirely self-contained except for power and antennas. Ideally, power will be drawn from the vehicle. The S and L-band antennas will be placed on the skin of the vehicle or in the avionics bay depending on vehicle requirements. The test will demonstrate TDRSS-mode ground- and space-based forward and return links, as well as the capability to receive GPS. Commands will be looped back internally and no connection with the vehicle Command and Data Handling (C&DH) system will be made. Dummy commands will be sent to the transceiver and looped back to prove the link in a realistic environment.

VIII. Technical Challenges.

Several technical challenges were identified and resolved; however, there remain a number of technical issues that require more investigation, analysis, and testing. The items are as follows:

1. Command Data Structure. Collaboration with experts on the formulation of a data format for this application will give rise to a command structure appropriate for this application. More research is required.

2. Mitigating multi-path on launch pad through liftoff. Obstructions caused by launch towers or other structures may require a stronger signal from the launch-head system.

3. The TDRSS has already been used to support ELV upper stages on Atlas, Titan, and the first two stages on SeaLaunch vehicles. Except for those range safety parameters imbedded in the upper stage telemetry, the TDRSS has no experience with the range safety forward link operations. Testing of new S-band range safety equipment will provide baseline data and experience for range safety support.

4. Seek authorization from the NTIA for TDRS High Power mode pointed at the Earth. NTIA waivers for potential PFD limitation may be required.

5. Prove that the LPT is a valid component for this application. All indications are that this transceiver will perform as required, but this is yet to be proven. An engineering model is currently under test, but this unit is not designed to function in the expected launch environment.

IX. Conclusion

As the pressure builds for the US space-lift ranges to upgrade and become more competitive in the world launch market, officials will continue to explore new ways to reduce cost and enhance capabilities. Although the existing system boasts an excellent public safety record, its extensive support infrastructure is costly to maintain and operate, thereby limiting launch turnaround time, launch site flexibility, and coverage area. To address these deficiencies, the Goddard Space Flight Center (GSFC) Space Network Project Office has worked for several years to devise a viable space-based range safety concept for providing launch vehicles command destruct and telemetry services. This concept grafts new technology onto a reliable existing space network. Although there are issues and technical challenges yet to be resolved, the GSFC, in conjunction with other NASA organizations and industry, is embarking on a development and test program centered around a low power transceiver capable of receiving multiple signals from ground- and space-based resources simultaneously and transmitting telemetry to the ground. The transceiver could be a building block for future space-based range applications. This program is expected to evolve into a full proof-of-concept phase in the next year or two and will culminate in flight demonstration tests with actual launch vehicles. Fortuitously, this endeavor comes at a time when a critical need and an enabling technology are converging.

Bibliography:

1.) Space Network User's Guide (SNUG-530), Revision 7, November 1995
2.) NASA/SN Support for Range Safety: Concept and Feasibility Study, July 1998
3.) STDN Operations Concept (532-OCD-STDN), Revision 4, November 1996
4.) Executive Order (EO) 12356, National Security Information
5.) NASA Automated Information Security Handbook, NHB 2410.9A, June 1993
6.) Range User Handbook, EWR 127-1, March 1995.